Carbon Emissions Scenarios for Asian Developing Countries: Baselines and Mitigation Opportunities

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1. INTRODUCTION

The earth's fragile atmosphere is changing with the continuing release of greenhouse gases (GHGs) around the world. At increasing atmospheric concentrations, GHGs are projected to raise the average world temperature, lead to a rise in sea level, and change seasonal and geographic precipitation patterns (1). These changes are expected to severely impact agriculture, ecosystems, water resources, coastal areas, and human health. Concern about such impacts led more than 160 nations to ratify the United Nations Framework Convention on Climate Change (UNFCCC), which was adopted in Rio de Janeiro in 1992 (2). The nations include those from the Organization for Economic Cooperation and Development (OECD) along with Russia and the Eastern European countries, known together as the Annex 1 countries; and a group, most of which are developing countries, referred to as the non-Annex 1 countries.

Developing countries today have lower income per capita and use fuel less efficiently than industrialized countries. This less efficient use of fuels stems from both a lack of state-of-the-art technology, and proportionally higher use of coal and biomass, which produce more of the greenhouse gas carbon dioxide (CO_2), per unit of energy than do petroleum products and natural gas. In addition, developing countries are net emitters of GHGs from the burning of forests for land clearing and the burning of nonrenewable biomass for cooking and other uses (3). Commensurate with the high economic and population growth in developing countries, GHG emissions there are expected to increase rapidly to match those from industrialized countries around 2018 (3a).

There is much debate about the extent of each country's responsibility for stabilizing global climate change. The 1997 meeting in Kyoto, Japan of the Third Conference of the Parties to the UNFCCC illustrated the sharp division between the 130 or so developing countries on the one hand and the industrialized countries on the other. The Annex 1 countries (which, except Belarus and Turkey, are listed as Annex B in the Kyoto Protocol) agreed to cap their emissions averaged over the period 2008 to 2012 at levels ranging from 7% below to 10% above their 1990 levels. The developing countries, often referred to as the "G77+China," resisted commitments to limit the growth of their GHG emissions on the grounds that these emissions have thus far been generated mainly by industrialized countries. Why, developing nations ask, should they assume responsibility for a problem they did not cause? The industrialized countries do not contest this position but point out that many emerging low-cost opportunities for reducing GHG emissions are found in developing countries. Can these opportunities be secured without affecting the economic growth and social fabric in these countries, particularly in view of their perennial shortage of capital for investment in new technologies and hard currency for the purchase of imported goods?

Early mitigation studies were led by research groups; the first effort was coordinated by the Lawrence Berkeley National Laboratory (LBNL) of the United States (5). The main focus of these studies was the preparation of long-term (through the year 2025) energy and carbon scenarios using a detailed end-use approach for 12 countries/groups of countries. A more ambitious effort, which included the estimation of costs of mitigation options, was initiated by the United Nations Environment Programme's Collaborating Centre for Energy and Environment (UNEP/CCEE) at the Riso National Laboratory in Denmark (6, 6a). In parallel, the Asian Development Bank (ADB) completed a broad climate change study that evaluated mitigation as well as vulnerability and adaptation options in several Asian countries (7).

In the early 1990s, governments in several industrialized countries, notably the U.S., Germany, the Netherlands and Denmark, initiated climate change studies in collaboration with developing countries. The U.S. undertook the U.S. Country Studies Program (CSP), in which 12 U.S. government agencies participate, to support climate change studies in 56 developing and transitional-economy countries in order to assist them in meeting their reporting requirements to the UNFCCC (8). A unique feature of the German and Danish efforts is their attention to regional mitigation options that may be pursued jointly by neighboring countries, such as the use of hydro power across southern Africa. Together, the bilateral efforts spent more than US $50 million on country studies, with the largest contribution from the US, about $35 million. Two other multi-country efforts supported by the Global Environment Facility (GEF) are also under way. One, administered by United Nations Development Programme (UNDP)/ADB, focuses on 12 Asian countries and is called the Asia Least-Cost Greenhouse Gas Abatement Study (ALGAS) (9)[1]; the other is administered by UNEP/CCEE and involves eight countries worldwide. Our analysis draws on Sathaye and Ravindranath (3b).

3. METHODS USED IN MITIGATION STUDIES

Two primarily different approaches, *"bottom up"* and *"top down,"* have been used for mitigation analysis in the energy sector. The bottom-up approach is more engineering oriented and begins by characterizing technologies and processes, combinations of which are then evaluated to assess their aggregate GHG emissions and costs. The top-down approach primarily evaluates the impact on a nation's Gross Domestic Product (GDP) of policy instruments, such as changes in carbon or fuel taxes. The studies evaluated in this paper are of the *"bottom-up"* type. These lend themselves to analysis of baselines and the impact of including specific technologies on GHG emissions.

Although the nature of GHG mitigation assessments varies depending on the GHG-producing activity or sector that is targeted, the bottom-up approach has a characteristic three-step structure: 1) evaluation of GHG reduction and carbon sequestration options, 2) development of a "baseline" scenario, and 3) development of GHG reduction or "mitigation" scenarios, including an estimation of scenario costs and GHG mitigation potential.

The first step, evaluation of GHG reduction and carbon sequestration options, involves screening options that are to be evaluated and collecting data on their technical performance, energy use,

[1] Data are drawn from individual country reports which are summarized in (9).

South Africa, and Mexico rank as the second, sixth, tenth, thirteenth and fourteenth largest contributors, respectively. Should China's emissions continue to increase at the 4.4.% rate that was estimated for the period from 1990 to 1996, they would reach the 1996 U.S. emissions level of 1,466 Mt C by 2010. India's emissions, growing at 6.7% annually, will exceed the 1996 U.S. figure by 2025. Future country-specific emissions scenarios reported in Table 1, however, project lower growth rates, which are discussed later.

Table 1. Emissions of carbon dioxide[a] from fossil fuel combustion and natural gas flaring

Country	1990[b]	1996[b] (AAGR)	Baseline Projections (AAGR) (final year) (Ref.)
China	620	805 (4.4%)	1855 (2.9%) (2030) (16) 1671 (3.1%) (2020) (15)
India	155	232 (6.7%)	960 (5.3%) (2025) (15) 630 (4.9%) (2020) (9)
South Korea	61	113 (10.3%)	284 (4.5%) (2020) (9)
South Africa	81	96 (2.8%)	
Mexico	79	86 (1.4%)	134 (4.9%) (2005) (14) 164 (4.6%) (2010) (14)
Other developing coun	735	928 (3.9%)	
Total developing countries	1731	2260 (4.4%)	4050 (2.4%) (2020) (3a)
OECD	2804	2943 (0.8%)	3570 (0.8%) (2020) (3a)
Eastern Europe/FSU	1296	833 (-7.4%)	2300 (4.2%) (2020) (3a)
Total World	5831	6036 (0.6%)	9910 (2.0%) (7000-12100)[c] (2020) (3a)

[a]In million tonnes of carbon. AAGR, Average annual growth rate; OECD, Organization for Economic Cooperation and Development; FSU, former Soviet Union.
[b]Reference 11.
[c]Intergovernmental Panel on Climate Change range of projections for scenarios 1992a through 1992f.

4.2 *Carbon emissions scenarios and the decomposition approach*

Each study that we evaluated has prepared a baseline or reference scenario and one or more abatement or mitigation scenarios of CO_2 emissions. We analyze the baseline scenarios by evaluating the factors contributing to CO_2 emissions, which can be expressed in terms of primary energy use, population, and a nation's GDP, using the following identity (13):

CO_2 Emissions = Population * GDP/Population * Energy/GDP * CO_2/Energy

Bottom-up approaches assume GDP and population growth rates as basic drivers for energy and CO_2 emissions growth. The energy/GDP ratio provides an indication of a nation's aggregate energy intensity or the energy needed to support a unit of economic activity; the CO_2/energy component provides information on the carbon intensity of the mix of fuels that supply primary energy. Changes in energy/GDP ratio may be caused either by structural change in the composition of GDP or by technical energy-efficiency improvements. The latter is influenced by the types of energy-efficiency mitigation options considered. Changes in the CO_2/energy component may be brought about by a change in the mix of fuels from coal to natural gas or other mitigation options.

economic decline in the East Asian countries will obviously lower projected rates and also affect energy consumption and consequent carbon dioxide emissions.

Table 2. Historical and projected growth rates[a]

Country	CO2	Population	GDP/ Capita	Energy/GDP	CO2/Energy	Reduction in target year	Published	Source
VIETNAM								
Historical	2.13%	2.23%	3.80%	-2.04%	-1.86%			4
Projected 1a (1994-2020)	8.40%	1.40%	6.02%	0.74%	0.09%		1998	9
NEPAL								
Historical	7.28%	2.57%	1.31%	4.10%	-0.71%			4
Projected 1a (1995-2030)	5.40%	1.60%	2.85%	-0.29%	1.15%		1997	14
BANGLADESH								
Historical	7.31%	2.38%	1.74%	3.75%	-0.56%			4
Projected 1a (1990-2020)	6.80%	1.50%	5.12%	0.56%	-0.47%	11%	1998	9
PAKISTAN								
Historical	6.76%	3.05%	2.78%	1.02%	-0.10%			4
Projected 1b (1991-2020)	6.50%	2.30%	3.32%	-0.85%	1.62%		1998	9
INDIA								
Historical	5.79%	2.14%	2.52%	1.13%	0.01%			4
Projected 1a (1990-2020)	4.90%	1.50%	4.14%	-0.76%	0.00%		1998	9
2a (1985-2025)	5.30%	1.25%	3.60%	0.48%	-0.09%	33%	1996	15
3a (1985-2025)	4.50%	2.00%	2.94%	-0.38%	-0.10%	11%	1991	5
3b (1985-2025)	4.50%	2.00%	2.94%	-1.05%	0.58%	11%	1991	5
CHINA								
Historical	5.06%	1.45%	6.96%	-3.32%	-0.04%			3
Projected 1a (1990-2020)	3.70%	0.90%	6.84%	-3.90%	0.10%		1998	9
2a (1990-2020)	3.10%	0.70%	4.17%	-1.53%	-0.19%	37%	1996	15
3a (1985-2025)	3.20%	0.80%	4.56%	-1.90%	-0.19%	23%	1991	5
3b (1985-2025)	3.20%	0.80%	4.56%	-2.37%	0.29%	21%	1991	5
4b (1990-2030)	2.90%	0.80%	6.35%	-3.73%	-0.29%	21%	1997	16
MYANMAR								
Historical	0.54%	2.03%	1.09%	-1.58%	-0.99%			4
Projected 1a (1990-2020)	5.30%	1.70%	4.42%	-0.94%	0.10%	24%	1998	9
PHILIPPINES								
Historical	2.20%	2.38%	0.40%	0.93%	-1.51%			4
Projected 1a (1990-2020)	5.90%	2.10%	2.94%	-0.38%	1.15%		1998	9
INDONESIA								
Historical	8.78%	1.96%	4.76%	2.48%	-0.42%			4
Projected 1a (1990-2020)	6.60%	1.30%	5.13%	-0.47%	0.57%		1998	9
2a (1985-2025)	3.90%	1.20%	1.78%	0.87%	0.00%	18%	1991	5
2b (1985-2025)	3.90%	1.20%	1.78%	0.49%	0.39%	18%	1991	5
3b (1990-2020)	7.10%	1.20%	5.73%	-1.21%	1.32%	20%	1997	17
THAILAND								
Historical	8.22%	1.92%	5.36%	0.79%	0.14%			4
Projected 1a (1994-2020)	5.60%	0.90%	6.05%	-1.21%	-0.09%		1998	9
2b (1990-2030)	5.50%	0.90%	3.87%	0.00%	0.67%	29%	1994	6
SOUTH KOREA								
Historical	7.36%	1.30%	6.95%	0.44%	-1.34%			4
Projected 1a (1990-2020)	4.50%	0.60%	4.47%	-0.86%	0.29%	16%	1998	9
2b (1985-2025)	3.30%	0.50%	5.17%	-1.89%	-0.39%	30%	1991	5

[a]Historical data 1971-95, except for Vietnam, 1984-95; Numbers in parenthesis indicate the scenario time period; Historical growth calculated as semi-logarithmic time trend; Projections as average annual growth. Projections (a) denote exclusion of biomass in primary energy consumption, projections (b) are inclusive of biomass.

fuel of choice for private producers because it requires less investment per kW of unit capacity than coal power plants. Greater natural gas use could hold projected higher carbon intensities in check.

The abundance of domestic hydro resources in a country can greatly reduce the CO_2/Energy ratio. The 1998 China ALGAS study's second scenario reports a similar sharp drop brought about by increased use of hydro, nuclear, and other forms of renewable energy. Where domestic renewable energy resources are scarce (India and South Korea), the CO_2/energy ratio does not decline as much between the two scenarios. Much of the energy demand in Indonesia is on Java, an island with limited renewable energy sources, which limits the potential for reducing the CO_2/energy ratio in Indonesia.

The CO_2/energy growth rate is high for Nepal, a small rural country, because of an anticipated shift away from biomass to kerosene and propane (LPG) for cooking and water heating. In Nepal, the share of biomass, which is assumed to be entirely renewable annually and thus to emit no net CO_2, declines from 95% in 1990 to 70% by 2030 (14) This decline causes Nepal's CO_2/energy growth rate to exceed 1.1%.

4.1.5 CARBON DIOXIDE EMISSIONS The historical carbon dioxide emissions from fossil fuel use increased in every country, with the growth rates high in Indonesia and Thailand at 8.8 % and 8.2 % per year respectively, Bangladesh, Nepal and South Korea between 7.2 and 7.4% per year, China, India and Pakistan between 5-7%, and a modest 2.2% per year in the Philippines and Vietnam. The projected growth rates are lower than the historical ones for most study countries, except Vietnam, Myanmar and the Philippines.

The contribution of the four factors to carbon dioxide emissions varies across countries (Table 3). Population has been the most important contributor to historical emissions growth in Pakistan, Myanmar, and the Philippines. Economic growth (GDP/capita) has been the largest contributor in the case of Vietnam, India, China, Indonesia, Thailand and South Korea. For the biomass-dominant countries, Nepal and Bangladesh, the largest contribution has come from the higher fossil energy/GDP ratio. The changing fuel mix played a significant role in Vietnam, where coal was backed out as oil share increased, and in Myanmar where natural gas displaced oil and coal.

In contrast to these historical trends, the most important contributor to future carbon dioxide emissions for all study countries is economic growth. It overwhelms the three other factors, reflecting the analysts' assumptions about strong economic growth in these countries. To a much lesser degree, population growth is the next biggest contributor to future carbon dioxide emissions, except in China and South Korea, where a declining energy/GDP ratio is projected to be the next most important factor.

Table 2 also shows the emissions reduction achieved in the mitigation scenario relative to the baseline one in the last or target year of each study. The extent of emissions reduction in each scenario depends on which mitigation options are already captured in the baseline scenario. If a substantial portion of the mitigation options are already included in the baseline scenario, because they are assumed to have been implemented for other good reasons, then the extent of

reduction in the mitigation scenario will be lower and vice versa. Second, in order to determine the extent of emissions-reduction in the mitigation scenario modelers chose (1) an emissions-reduction target or (2) they ran the model until demand or resource constraints dictated that no further reductions could be achieved. For the Indonesia study a 20% target was aimed at. For the 1996 China and India studies, the model was run until it ran into constraints on capital and foreign exchange. For the 1991 LBNL studies, the modelers used their best judgement on the extent to which technological change could occur by the 2025 target year. Each approach is eventually constrained by the types and numbers of mitigation technologies that are included in the analysis.

5. COST OF MITIGATION OPTIONS

5.1 *Cost of mitigation options*

Each study country has identified many mitigation options that could be pursued to reduce GHG emissions relative to the baseline scenario. The options are ranked in order of increasing cost so as to provide guidance to policy makers regarding priorities for implementation. These priorities can shift as attributes other than cost are considered.

Most mitigation analyses define costs so as to include equipment, labor, materials, and fuels. Transaction and administrative costs of actually implementing an option are often not included in these analyses. The life-cycle cost of a mitigation option may be higher or lower in comparison to its alternative in the baseline scenario. For many reasons, which have been collectively called "market barriers," a mitigation option with lower life-cycle cost, i.e., that is cost-effective, may not show up in the baseline scenario. Such options are known as "no-regret" options because their inclusion in a mitigation scenario will lower the cost of providing energy service, so the mitigation scenario will exhibit "negative" cost relative to the baseline scenario. If the monetary and other costs of overcoming market barriers are not prohibitive, it is clearly worth pursuing a negative cost option before pursuing options with positive costs.

Optimization models are used to develop scenarios or combinations of mitigation options that minimize the cost of providing energy services for a country's economy. Results from these models are often presented in terms of the costs of a scenario rather than costs of individual options. Key results from GHG mitigation studies for India (21) and China (22) are analyzed by Sathaye et al. (15). The two studies used variants of the ETO engineering optimization model.

For each country, two scenarios were analyzed for the period from 1985/1990 to 2020/2025. The first is a "Current Trends" or baseline scenario and, the second scenario is a "Low Carbon" or mitigation one. Values of factors such as population growth, economic activity (Table 2), sector structure, and technical progress are assumed as exogenous inputs into the analysis of each country. Results from the studies are summarized in Table 4.

For India, the Low Carbon case reduces the cost of providing energy services by 13% in 2025 while reducing carbon emissions by 29%. The CCC is thus negative at -58 US $/tC. The negative cost options include opportunities to improve energy efficiency as well as switching to natural gas. Mongia et al. show that efficiency improvements and improved fuel allocation

in the model. The mitigation scenario aimed to reduce CO_2 emissions by 10% from the baseline in 2010 and 20% in 2020. The total annual investment for the energy system (including public and private expenditures) in 2020 would be 1989 US$47 billion for the baseline scenario and $50 billion for the mitigation scenario.

5.2 *Foreign Exchange And Investment Requirements*

Decisions regarding fuel and technology options in developing countries are often based on the investment and foreign currency implications of the options rather than annualized costs. Investment and foreign currency consequences of pursuing mitigation options were studied for China, and India (Table 5). For India, the combined investment and foreign exchange required for the energy sector as a share of GDP is 10.1% in 2025 in the Current Trends scenario and 9.6% in the Low Carbon scenario. In the latter, natural gas imports reduce the capital cost of electricity generation but add to foreign exchange requirements.

Table 5. Investment and foreign exchange as percent of gross domestic product

China	1990	Current Trends 2020	Low Carbon 2020
Investment (%)	4.6	2.8	2.3
Foreign Exchange (%)	-1.2	-0.1	5.1
India	1985	Current Trends 2025	Low Carbon 2025
Investment (%)	4.1	4.8	3.4
Foreign Exchange (%)	1.9	5.3	6.2

In China, energy system investment as a percentage of GDP in 2020 is less in the Low Carbon scenario, but the foreign exchange requirement is much higher (5.1% of GDP vs. -0.1% in Current Trends). Holding the foreign exchange outflow to 5% of GDP limits the extent to which emissions can be lowered through import of natural gas. A more recent Chinese study (9) corroborates these findings and shows that 25% emissions reductions are possible compared to the baseline in 2020, with only a modest share, about 6%, of the GDP going for investment and fuel imports compared to 5% in the baseline scenario. The share actually declines from 1990 as energy efficiency improvements lead to a sharp decrease in the energy/GDP elasticity, to 0.42, down from 0.5 in the baseline scenario.

6. MULTICRITERIA EVALUATION OF GHG MITIGATION OPTIONS

The studies reported above provide carbon mitigation scenarios based on the economic potential of each mitigation option,[2] which ignores the many market barriers to their penetration. Barriers to improvements in energy efficiency or fuel switching may arise for or from any of the participants in energy transactions. These include energy consumers, end-use equipment manufacturers and providers, producers and distributors of energy, actual and potential cogenerators, local/national financial institutions, governments, and funding agencies (23). Policies and measures may be necessary to overcome these barriers. Cost analysis by itself is

[2] Economic potential is the portion of the technical potential for GHG emissions reductions or energy-efficiency improvements that could be achieved cost effectively in the absence of market barriers (IPCC, 1997) (34). Technical potential is defined as the amount by which it is possible to reduce GHG emissions or improve energy efficiency by using a technology or practice in all applications for which it could technically be adopted, without consideration of its costs or practical feasibility.

The "pessimism" of the top-down approach originates from the assumption that the present technology mix results from efficient behavior by consumers and firms under prevailing economic conditions. The application of the top-down approach to developing countries suffers from unrealistic assumptions about the existence of “free markets.” Recent approaches, one for Venezuela (26) and another for Nigeria (27), have tried to break this mold.

7.1 Top-down models

Several top-down models have been used to analyze the GDP impacts of tax policies to reduce carbon emissions (28, 29). We report on two of these models, which have been used to analyze GDP impacts of mitigation policies in developing countries.

A model similar to the OECD *General Equilibrium Environmental (GREEN)* model has been developed in China by Zhang (30). The CGE-China model is a time-recursive dynamic model. Energy use is disaggregated into four categories: coal, oil, natural gas, and electricity. The model has been calibrated to a 10-sector social accounting matrix (SAM) version from 1987.

One drawback of the model is that it is not able to represent specific technologies. The production relationships used in the model are averages for the whole energy sector, for example, and tend to obscure diverse underlying processes and behavior. The *Second Generation Model* (SGM) addresses this limitation by utilizing technologies rather than sectors as its fundamental unit of disaggregation among production activities within an otherwise conventional CGE structure. The SGM model has 20 sectors, with the energy sector divided by electricity generation and fuel supply technologies. Capital stock, however, is not malleable and cannot be shifted from one economic sector to another. The model can represent individual country data. (We report on its application to India below.) The SGM model, however, lacks a detailed representation of energy-consuming sectors; in addition, technological change, a key parameter in determining the extent to which energy efficiency may improve has to be input exogenously.

7.2 Results

The baseline scenario for the CGE-China model extends to 2010. The aggregated results show relatively small decreases in growth and consumption, especially for the 20% emissions reduction objective. The results of the CGE-China model are fairly close to the results of the OECD global model GREEN (31). The main reason for this is probably the assumption of operational markets for factors of production, products, and foreign exchange. It is questionable whether this assumption holds over a time horizon of only 20 years in China. An interesting result of the different scenarios is that transportation is hardly affected by a 20% reduction in emissions, but a 30% reduction entails a transportation decrease of 14%. This indicates that all "cheap" energy options are utilized to achieve the 20% reduction and that any reduction targets beyond 20% will result in considerable macroeconomic losses.

India. A top-down model originally designed for industrialized countries, the Second Generation Model (SGM) (32), was applied to India (18). Carbon emissions in the SGM reference scenario are three times higher in 2030 than in 1990. A “1 X” mitigation scenario assumes the application of a carbon tax to stabilize future carbon emissions at the 1990 level. A “2 X” scenario assumes

India to pursue a carbon-friendly strategy as a baseline scenario. An important caveat here is that the extent of emissions reduction and the corresponding costs in the mitigation scenario are estimated relative to the baseline, whose definition is open to interpretation and judgement about a country's future. If reforms in India capture the full energy efficiency potential and fuel allocation is least-cost, then a mitigation scenario for India would also show positive cost.

Although the annualized or life-cycle cost may be negative for India, it would be difficult for the country to raise the necessary capital or hard currency to pay for renewable energy sources or imported natural gas. On the other hand, it may cost more for China and South Korea to reduce their emissions beyond the baseline scenario, but, as a proportion of GDP, the increased capital and hard currency requirements for these countries would still be modest and affordable.

Are carbon taxes a feasible alternative for reducing emissions? There have been only a handful of studies which have evaluated this question (for China, Egypt, India, Nigeria, and Venezuela); for both China and India the GDP growth rate slows with carbon taxes. A non-Asian study for Nigeria shows, however, that the decline can be offset by improving productivity of energy use. The policy prescription would then be to implement initiatives to improve energy efficiency along with an increase in carbon taxes.

The mitigation studies we have reviewed show that many more cost-effective GHG mitigation options could be pursued in developing countries. The implementation of mitigation options faces many barriers at the macro, sector, and project levels. Removal of these barriers will improve developing countries' access to financing and advanced technologies, both of which are perennial concerns for developing country governments. Policy reforms to encourage environmental sustainability, increased productivity, improved infrastructure and planning, and carbon-project monitoring are essential for large-scale implementation of mitigation options. A large national and international financial commitment is also necessary (33).

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